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Art. IX.—*On an Inclusion of Ordovician Sandstone in the Granite of Big Hill.*

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(Howitt Natural History Research Scholar, 1920).

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1—Foreword.

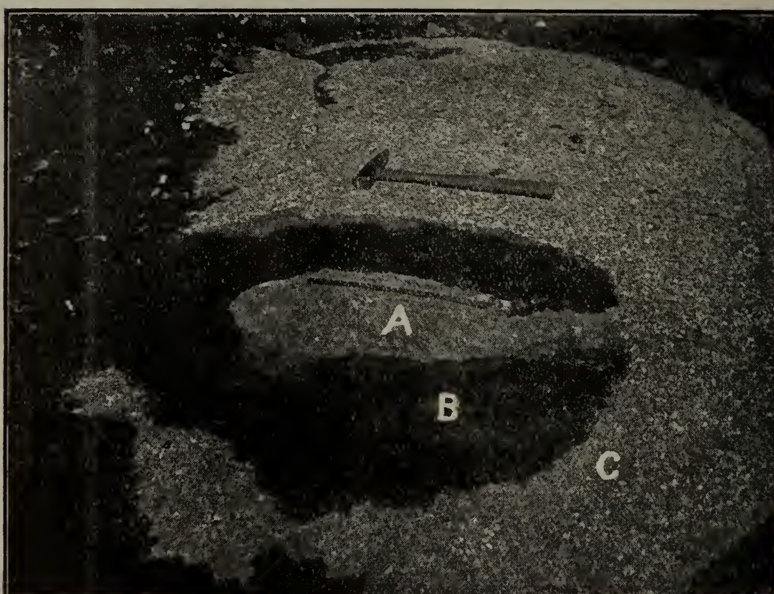
Big Hill lies some eight miles S.W. of Bendigo, overlooking the wide expanse of undulating plain extending southwards to Harcourt, Castlemaine and Maldon. Big Hill is one of a series of ranges surrounding the saucer-shaped Harcourt granitic area, all being in the nature of residuals, owing their existence to the metamorphism and induration of the Lower Ordovician at the contact of the granitic intrusion. The original sediments near Big Hill have been altered in places to quartzite and mica hornfels, chiastolite often showing in the slates. Well preserved specimens of the altered Ordovician are practically unobtainable, the rocks having been weathered and leached to a considerable depth, in some places below 400 feet.

The exact line of contact between granitic intrusion and Ordovician is, at Big Hill, rather indeterminate owing to the accumulation of hill wash and alluvium on the hill slopes, and at the foot of the hills. However, in places large granitic boulders are found protruding above the surface, and by closely following the beds of the small creeks, the limits of the granitic mass may be very closely delineated.

2.—Ordovician.

The Ordovician of Big Hill forms the southern extension of the Bendigo Goldfields, and there are probably three horizons of the Lower Ordovician represented here—Lancefield, Bendigo and Castlemaine. The well-formed anticlines and synclines so typical of Bendigo extend south-west, right up to the Harcourt granitic mass at Big Hill, remaining undisturbed both in dip and strike at the contact. In fact, the Big Hill range may be looked upon as the southern limit of the Bendigo Goldfields, for the slopes of the range have been costeened and scratched for gold in the past, although in rather a spasmodic manner.

The sediments are represented by sandstones and slates of varying composition and texture, there being every gradation between the normal sandstone and normal slate. In Bendigo these have been mineralised to some considerable extent by the impregnation of quite a high percentage of pyrite, with lesser amounts of arsenopyrite, galena and sphalerite. At Big Hill these sulphides are practically absent, but the Ordovician has been metamorphosed fairly extensively with the formation of micaceous sandstone (in some places the mica is in quite coarse plates), whilst the occurrence of chiastolite in the slates is common throughout the metamorphic aureole.



Inclusion of Country Rock (A), surrounded by Basic Segregation (B), in Granite (C).

3.—The Harcourt Granite Intrusion.

The granitic mass of Harcourt has never been critically examined, but it has generally been looked upon as a granodiorite similar to that of Macedon, Dandenong, Mount Eliza and Mount Martha. The high percentage of SiO_2 and the possibility that many of the twinned felspars may be anorthoclase, as will be indicated later, point to the probability of the rock being a soda-rich granite similar to that at Station Peak. In fact, it is remarkably like this latter, often containing large phenocrysts of felspars although perhaps not as large as the You Yangs specimens.

Numerous veins of aplite and tourmaline aplite traverse the granitic mass, and also run out into the Ordovician at the contact. It is, however, with the method of intrusion and the differentiation of the Harcourt plutonic magma that this paper is more directly concerned.

The accompanying photograph is of an inclusion of country rock in the granite near Big Hill. This specimen occurs on the south slope of Big Hill, in the bed of a small tributary to Bullock Creek, and is situated at least 200 yards from the contact of the intrusion with the Ordovician. At this point the tributary has exposed the bare surface of the granite over an area of a few square feet, and has rounded and smoothed the rock surface considerably. As will be noted from the photograph, the inclusion (A) stands up in relief from the granite surface (C). Surrounding the inclusion, except for two inches on the right-hand side, is what appears to be a basic segregation (B) from the hand specimen, and this latter, in contrast to both Ordovican inclusion and surrounding granite has been eroded to a maximum depth of three inches below the granite surface. Two very thin, light-coloured veins or threads cut through both the country rock and segregation, and apparently run into the granite at the side where the granite is in actual contact with the sandstone inclusion. The original sandstone has been altered to a considerable extent.

Description of specimens:—

Granite, Big Hill.—A light grey apparently normal granite of quartz, felspar and biotite, often containing fairly large crystals of felspar. Under the microscope shows typical granitic texture. Abundant quartz and orthoclase in large allotriomorphic crystals, twinned and zoned felspars ranging from oligoclase to albite in smaller crystals, but relatively abundant and approximately equalling orthoclase in amount. Owing to the extremely minute twinning of some of the felspars, they may be possibly anorthoclase. In two or three of the large orthoclase crystals extremely thin lamellae can be just barely detected, pointing to a possible soda variety. Microperthitic intergrowth of albite in orthoclase is common. Brown biotite altering in places to chlorite is an essential constituent. Accessories are apatite (occasionally in large crystals), zircon, and rarely sphene.

A determination of the silica percentage gave a result closely approximating Daly's average of 69.92 for true granites—this result is given later. The silica percentage is rather high for a granodiorite, and it is thus very possible that some of the apparent plagioclase felspars may be anorthoclase.

Basic Segregation around Inclusion, Big Hill.—A dark-grey, fine to medium-grained holocrystalline rock, consisting in the hand-specimen of quartz, felspar, and abundant biotite. Both in texture and appearance, it is quite distinct from the surrounding granite.

Microscopically the rock is seen to be much finer in texture than the granite. There is a large increase in plagioclase, decrease in percentage of quartz, whilst orthoclase is not at all common. There is also a slight increase in biotite, whilst apatite, though still relatively abundant, never occurs other than as small crystals. Other accessories are zircon, sphene, and a little magnetite in biotite. Biotite altered in part to chlorite.

This rock is the equivalent of a typical granodiorite, the silica percentage (see later) approximating closely to Daly's average of 65.15 for granodiorites.

Inclusion of Altered Sandstone, Big Hill.—A fine-grained, light-buff coloured rock, containing a good deal of mica.

Microscopically the section shows a granular quartz mosaic, with occasional sub-angular grains of orthoclase and plagioclase. Abundant biotite, generally occupying interstices between quartz grains. Detrital zircon and apatite, whilst needles of apatite are often included in the quartz grains.

The rock is evidently a re-crystallized sandstone.

There are two possible modes of formation of the basic segregation open to discussion, explained by each of the two hypotheses of magmatic differentiation postulated by Daly and Bowen respectively.

4.—Mechanics of Intrusion.

(a) Accepting first Daly's hypothesis of magmatic stoping combined with marginal assimilation, we would picture the molten igneous mass intruding its way up through the Ordovician by magmatic stoping, assimilating the country rock as it progresses. The particular inclusion at Big Hill would be looked upon as a fragment of Ordovician which had not been entirely digested, whilst the surrounding basic segregation would be explained as granite which in the immediate neighbourhood of the Ordovician had its composition altered by solution of the sedimentary rock. Under normal circumstances of slow diffusion, the alteration of composition of the granite would be a gradual and progressive one, from a maximum at the surface of the country rock outwards to the normal granite. The acute change of composition of this segregation at the margins would, however, be explained by picturing the fragment as being localised to a certain definite neighbourhood until a state of equilibrium was reached so far as slow diffusion was concerned. For some short distance around the fragment of sandstone, the granite magma would now be of an approximately similar composition throughout. If now further movement of the magma took place, so that the position of the fragment were altered—as, for instance, if the sandstone commenced to sink—then this equilibrium would be immediately disturbed. A certain amount of the surrounding altered magma would be carried with the inclusion and corroded by the magma to some extent, until finally, the whole granitic intrusion crystallized out.

On this hypothesis of magmatic stoping and marginal assimilation it would, as a necessary corollary, be presupposed that the segregation immediately surrounding the fragment would be of a composition intermediate between that of the granite, and included country rock, i.e., an inclusion of higher SiO_2 content than the granite should give a surrounding segregation of more acid composition than the granite, while a more basic inclusion would give a segregation of less acid composition. The upholding of this supposition by chemical analysis would go a long way towards the acceptance of the hypothesis, whilst a negative result from chemical analysis would mean the absolute rejection of the hypothesis of marginal assimilation so far as this occurrence is concerned. The following are the average silica contents of the three rock types as shown by analyses kindly undertaken by Miss McInerny, of the Geology School, University of Melbourne:—

Country rock (sandstone)	78.30 per cent. SiO_2
Segregation	65.30 per cent. SiO_2
Granite	69.79 per cent. SiO_2

The segregation is thus not of an intermediate composition, the SiO_2 content being lower than either of the other two; hence the hypothesis of marginal assimilation as applied to the explanation of the origin of the segregation surrounding the Big Hill inclusion of country rock must be rejected.

(b) The theory of magmatic differentiation upheld by Bowen affords an excellent explanation of the origin of the basic "aureole" to the inclusion. This "aureole" would represent a portion of the chilled border facies attached to the roof, and subsequently broken off with some of the country rock, to be incorporated in the parent magma. At the intrusion of the molten magma, the cooling at the marginal walls would be ahead of the cooling of the main mass, and here there would probably crystallize out a rock of the same composition as the molten magma at that instant. The main mass of the magma would remain still liquid, and as cooling progressed differentiation by sinking of crystals would continue, the liquid magma becoming more and more acid until, ultimately, the whole would crystallize out, producing as an ideal result an acid alkalic magma with a less acid and more calcic border (the chilled border facies). But prior to the crystallization of the main liquid magma, picture a rejuvenation in the mechanical activity of the magma brought about perhaps by earth movement, so that magmatic stoping commenced afresh. Picture also a small roof pendant of country rock projecting into the magma, and around which a "chilled border facies" has crystallized. With the renewal of magmatic stoping this roof pendant and its attached basic granitic border will break away from the main country rock, and sink into the liquid magma to be perhaps slightly corroded, but finally isolated in the granite on solidification of the magma. This will also explain the curious shape of this particular inclusion of Big Hill—a fragment of country rock (about six inches wide and two feet long), surrounded by a basic segregation except on that side which may be pictured as the area of attachment to Ordovician roof.

This, then, is quite an acceptable explanation of the origin of this inclusion, and considered as such, the Big Hill inclusion affords excellent evidence of the possibilities of both Daly's hypothesis of magmatic stoping, and Bowen's research on the differentiation of rock magmas, particularly as applied to the origin of "chilled border facies."